26904-6002-TU-00

NASA CR-
147700

FINAL REPORT
FOR
SPACELAB COST REDUCTION ALTERNATIVES STUDY

EXECUTIVE SUMMARY
VOLUME I

NAS 9-14484
EXHIBIT B

1 FEBRUARY 1976

Prepared for
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(NASA-CR-147700) SPACELAB COST REDUCTION ALTERNATIVES STUDY. VOLUME 1: EXECUTIVE SUMMARY Final Report (TRW Systems Group) 47 p HC $4.00 CSCL 22E

N76-24315

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G3/15 41803

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This document represents one part of the Final Report for the Spacelab Cost Reduction Alternatives Study, prepared by TRW Systems under Contract NAS9-14484/Exhibit B with NASA, Lyndon B. Johnson Space Center. The complete list of documents which make up the Final Report is as follows:

- Volume I - Executive Summary
- Volume II - Final Briefing
- Volume III - Crew Training Task Analysis

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1. INTRODUCTION

The objective of the Cost Reduction Alternatives Study (Study II) was to define and compare alternative approaches to Payload Operations Planning and Control and Flight Crew Training for Spacelab payloads with the goal of:

- Lowering FY 77 and FY 78 costs for new starts
- Lowering costs to achieve Spacelab operational capability
- Minimizing the cost per Spacelab flight.

These alternatives attempt to minimize duplication of hardware, software and personnel and the investment in supporting facility and equipment. The alternatives were derived from the basic NASA guidelines for the study. Of particular importance to the TRW effort is the possible reduction of equipment, software and manpower resources such as computational systems, trainers and simulators.

1.1 SCOPE OF STUDY

The Payload Operations Planning and Control task included the Spacelab payload preflight planning, realtime replanning, and experiment data preprocessing functions of STS operations. The scope of the Flight Crew Training task included the training of the experiment crew necessary to assure their adjustment to the space environment, their ability to live and work in the Orbiter and Spacelab and to operate Spacelab systems in support of the experiment operations.

Each of the tasks within the Cost Reduction Alternative study was established to define and compare logical alternative approaches to the functions being considered and to determine the sensitivity of the results and conclusions to significant variations in assumptions and constraints.

The general approach was developed to accomplish the following:

- Prevent the buildup of facilities and their support equipment and personnal in advance of traffic buildup.
- Reduce the stress toward optimizing mission parameters such as flight crew timelines, use of Shuttle payload weight, and use of utility resources.
- Accept lower confidence levels in reliability and checkout status of experiment hardware and software than on Skylab.

- Minimize or avoid mission dependent hardware and software changes between flights.

To accomplish these objectives the following tasks were performed:

Flight Operations Planning and Control

1) Operations Concepts that Reduce Manpower
2) Spacelab Payload Operations Center Requirements
3) Experiment Data Preprocessing Alternatives

Flight Crew Training

1) Crew Training Task Analysis/Requirements Definition
2) Training Equipment Evaluation
3) Training Equipment Recommendations.

Crew training studies were constrained to:

- Experiment/Spacelab Interface Training
- Habitability and Safety
- Spacelab Systems Operations and Maintenance.

The definition of the skills and training required to become proficient in the operation and maintenance of the experiment systems was not a part of this study. Assumptions regarding the duration, equipment or location of this training were made as necessary.

To develop Alternative program scenarios, many of the study tasks require sensitivity analysis to payload type and flight rate. To assure continuity between all of the tasks several specific payloads and reference missions were selected. The traffic models and reference missions were developed by NASA Headquarters/Mission and Payload Integration and are representative of all Spacelab payloads. Five missions and three traffic models were defined as shown in Table 1-1.

Table 1-1. Spacelab Missions and Traffic Models for Cost Reduction Alternatives Study

TRAFFIC MODEL	CALENDAR YEAR											
	80	81	82	83	84	85	86	87	88	89	90	91
TM-1	2	6	12	17	19	21	21	24	24	24	27	29
TM-2	2	4	7	11	13	13	14	15	16	16	16	16
TM-3	1	2	5	7	8	9	9	10	10	10	10	10

SPACELAB MISSIONS

- COMBINED ASTRONOMY
- AMPS
- LIFE SCIENCES
- MULTI-APPLICATIONS SPACELAB
- ATL

1.2 RECOMMENDATIONS

The Cost Reduction Alternatives Study has identified many alternatives which could be implemented in the Spacelab flight planning, real-time replanning and crew training plans and procedures. However, each payload represents a unique set of operational requirements. A summary of these requirements is shown in Table 1-2. The table addresses the three major factors which define flight operations and training approaches:

- Number of experiment systems
- Complexity of the flight - interaction of flight sequence, vehicle and environment
- Real time interaction of scientific results and flight plan.

Table 1-2. Summary of Payload Operational Requirements

PAYLOAD	NUMBER OF EXP. SYSTEMS	COMPLEXITY			REAL TIME INTERACTION	
		CONSTRAINED ATTITUDE/ POINTING	CONSTRAINED ORBITAL CONDITIONS	CONSTRAINED ORDER OF PERFORMANCE	RESULTS CHANGE PLAN	RESULTS CHANGE PROCEDURES
AMPS	8	30				
ATL	12	EARTH				
LIFE SCIENCES	2	NO				
MULTI-APLS	6	EARTH				
COMB. ASTRO	4	400 IPS				

HIGH

MODERATE

LOW

Each of these factors translates into the appropriate degree of crew training and crew involvement in experiment hardware development, and the complexity of the flight planning and real time ground support functions.

Considering the previous discussion and the results of the CRAS studies the following recommendations are made:

1) Flight operations and crew training plans must be flexible to allow for the significant difference in requirements between payloads.

2) Lead Payload Centers should be established for each Spacelab Cargo/Payload to assure lowest cost operations plans are adopted.

3) Adopt decentralized flight planning at each lead center. Use institutional computer systems and limit planning iterations.

4) Consider the combination of some aspects of flight planning and flight crew training.

5) Plan for a modular Payload Operations Center (POC), based on the use of mini/micro processors.

6) Review the real need for high rate science data in the POC.

7) Use upgraded hi-fi mockup and aft flight deck trainer/simulator combined with SMS for training.

8) Use engineering model and Level II and III integration facilities for "refresher" training.

9) Plan for experiment CDMS emulation and workstation at each payload center for experiment/Spacelab subsystem interface training.

2. PAYLOAD OPERATIONS PLANNING AND CONTROL

The general objective of this task was to search for approaches in operations planning and control which would minimize duplication of functions and hardware and reduce the cost per flight, and the investment in supporting facility and equipment hardware, software and personnel compared to the approach on which the Spacelab Baseline Program Plan was based. An evaluation of the baseline plan and the results of the data preprocessing study were presented at mid-term. Following the mid-term briefing TRW was directed to perform the following specific tasks:

1) Identify ways to reduce manpower for both real time replanning (RTRP) and flight planning.

2) Identify equipment, manpower and facilities required for the Payload Operations Center (POC) by discipline, for each traffic model.

2.1 OPERATIONS CONCEPTS THAT REDUCE MANPOWER

Lower costs for payload flight planning can be achieved by careful attention to four major factors. These four factors have been identified as important for reducing both non-recurring costs (e.g., new computers and software) and recurring costs (e.g., manpower per flight). In the material that follows, each factor is analyzed to determine its contribution to cost-savings, and implementation methods for achieving these lower costs. The factors are:

- Minimize Contingency/Malfunction Planning
- Minimize Flight Planning Iterations
- Maximize Use of Institutional Computer Systems
- Maximize Common Use of Manpower.

2.1.1 Minimize Contingency/Malfunction Planning

The likely payload contingencies, their causes and remedial actions have been identified. It is important to note that all elements of the flight (Orbiter, Spacelab, experiment equipment, procedures and crew timelines) will be developed to minimize the occurrence of malfunctions or contingencies; accordingly, it should be expected that malfunctions and contingencies will decrease as the STS and payload technology mature. The need for payload contingency planning will correspondingly decrease.

The Probable Actions shown in Table 2-1 are all withing the capabilities of the POC and its supporting complement of Principal Investigators, experiment engineers and flight planners. The resources of the MCC will provide comparable support for workaround procedures for orbit insertion errors and Spacelab subsystem malfunctions. From Skylab, experience shows that the flight crew is also capable of corrective actions for payload malfunctions and contingencies.

Table 2-1. Most Contingencies are Solved by Change to the Timeline

EXPERIMENT CONTINGENCY FACTOR	PROBABLE CAUSE	PROBABLE ACTION	GENERAL CHARACTERISTICS
EXPERIMENT EQUIPMENT PERFORMANCE	EQUIPMENT BREAKDOWN	• FAULT ISOLATION • WORK AROUND	• LARGE NUMBER OF VARIATIONS • LARGELY UNPREDICTABLE • GENERALLY ONLY CAUSES LOSS OF EXPERIMENT TIME • MOST LIKELY ACTION IS A CHANGE IN THE TIME LINE
ORBITAL DEVIATIONS	VARIATION IN LAUNCH TIME, INSERTION ORBIT, ETC.	• REVISED TIME LINE	
NATURAL PHENOMENA	OCCURENCE OF FLARES, WEATHER, ETC.	• REVISED TIMELINE	
HUMAN FACTORS	VARIATION OF CREW PERFORMANCE IN ZERO-G ENVIRONMENT	• REVISION OF EXPERIMENT PERFORMANCE TIME • REVISED TIME LINE	
SCIENTIFIC DATA	SCIENTIFIC PHENOMENA NOT AS EXPECTED	• RECONFIGURATION OF EQUIPMENT	

2.1.2 Minimize Experiment Planning Iterations

Manpower and computers hours for payload flight planning are directly related to the number of times the flight plan is updated. It is recommended that a new plan, or an update of an existing plan, be accomplished only at the following times:

- When a flight plan is needed to support experiment equipment design specifications, or to assemble requirements for flight support from the STS, the launch site, communications networks and other support agencies.

- When hardware test data become available for integrating into detailed timelines, procedures, consumables and pointing analysis. As a subset, refinement of a detailed flight plan may be necessary on the basis of simulation of experiment operations and training exercises.

The advantage of limited iterations is in a reduction of costs (manpower and computers) from the costs of continuous flight planning during the preflight periods.

For Spacelab payloads, Figure 2-1 shows the minimum flight-plan iteration requirement together with their intended purpose. Flight plan "A" will be used to define total flight characteristics and constraints that must be considered in design and test of the experiment equipment. Flight plan "B" is a detailed plan that will include experiment timelines, procedures, consumables and pointing, all of which should be compatible with the actual flight hardware. Flight plan "C" is an update that considers the impact of simulations and integrated crew training; this flight plan becomes part of the Flight Data File.

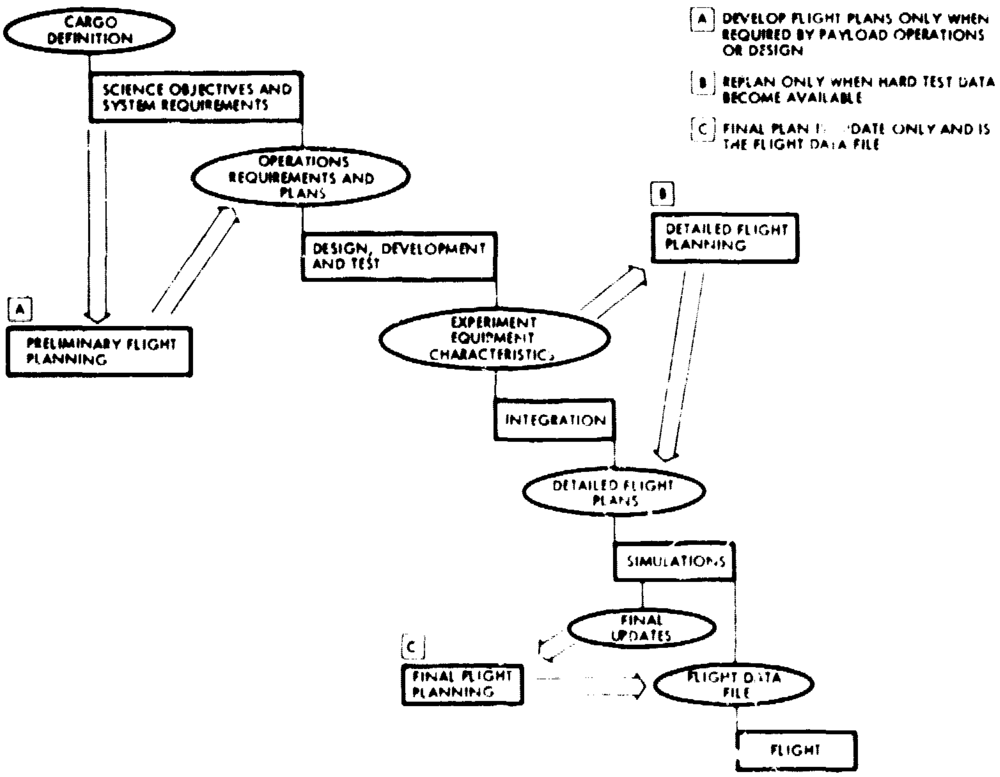


Figure 2-1. Experiment Flight Planning Iterations

Manpower estimates were developed for the three iteration planning scheme. Experienced flight planners are available both within NASA and in industry, and it is assumed such people would be assigned

to the flight planning function. The estimates for manpower were provided by TRW people who supported the flight planning for Skylab, Apollo and ASTP, and who have reviewed the candidate Spacelab payloads. As a baseline, Multi-Applications payloads are considered to be of average complexity and are used for initial manpower estimates. Manpower estimates are shown in Figure 2-2 for the three iterations to the flight plan and for a limited degree of flight plan maintenance. The values are consistent with the plan described in Figure 2-1.

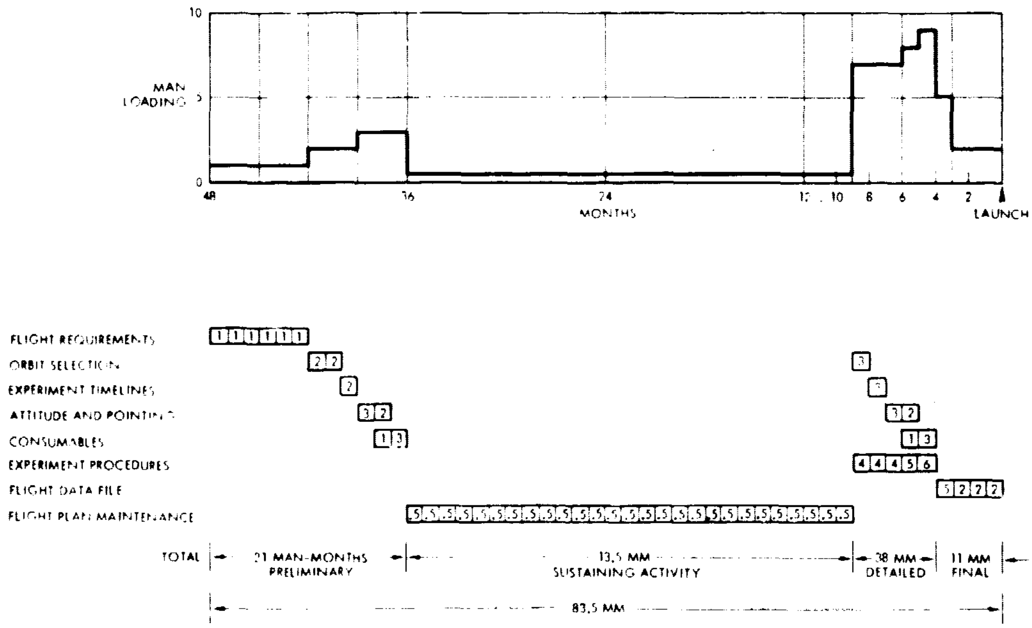


Figure 2-2. Nominal-Payload Man-Month Estimates For Flight Planning

Flight plan maintenance is shown for a period that is typical of the manufacture and test of new experiment equipment. For reflights, this period would be shorter because this equipment would require only refurbishment or minor modifications. Flight plan maintenance would be reduced accordingly.

The manpower estimates are also consistent with use of the computer hours estimated elsewhere in this report. It is also assumed that the flight planners are collocated with the payloads' system engineers and have ready access to Principal Investigators.

Spacelab payload equipment is expected to be used on successive flights with only slight modification between flights. It will thus be possible to reuse large portions of the previous flight plan, resulting in lower manpower requirements for planning. For example, procedures for operating the equipment will change only slightly and much of the Flight Data File can be used again. Also, sustaining activity will be appreciably lower than for the first flight of the payload because the equipment-procurement cycle will be greatly reduced in scope and time. Based on the above, estimates for man-months to plan repeat flights are significantly lower than for the first flight of a payload, as shown in Table 2-2.

Table 2-2. Flight Planning Man-Month Requirements by Flight Type

PAYLOAD DISCIPLINE	MANPOWER REQUIRED - MAN MONTHS		
	FIRST FLIGHT	RE-FLIGHT	30-DAY FLIGHT
AMPS	109	62	123
ATL	121	56	139
LIFE SCIENCES	65	18	70
MULTI-APPLICATIONS	83	36	95
COMBINED ASTRONOMY	87	40	100
FIRST MISSION	73	-	-
MAJOR DIFFERENCE IN PLANNING ACTIVITY	-	• EXPERIMENT PROCEDURES • FLIGHT DATA FILE • SUSTAINING ACTIVITY	• ATTITUDE AND POINTING • CONSUMABLES

For 30-day flights, attitude and pointing must be planned for larger number of targets, and consumables planning becomes more complicated because the Spacelab's limited resources must be stretched out over a longer period.

2.1.3 Maximize Use of Existing Computer Resources

Payload flight planning involves use of computers for many analyses, such as determination of pointing angles, consumables profiles and crew timelines. Within NASA, a great amount of computer hardware and software is available and can be used for Spacelab payload flight planning. This capability is enhanced by the fact that preflight planning is not time-critical, making it possible to use institutional resources in a batch-processing mode if interactive capability is not available.

The analysis has considered the capabilities of payload Lead Centers to support the anticipated flight rates, leading to recommendation that existing computer resources be used for payload flight planning.

Estimates for the computational workload for payload flight planning have been developed as part of the analysis. The level of flight planning is consistent with the other manpower reduction factors. Univac 1108's have been used for estimating computer hours because this computer is widely used by candiate Lead Centers. A typical computational workload preflight is shown in Figure 2-3.

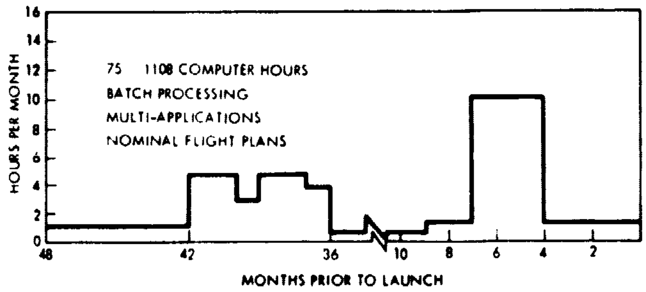


Figure 2-3. Typical Computational Workload

Multi-Applications payloads are "average" for the Spacelab payloads, and the computational workload for this payload is shown. The computational hours/month are for the first flight of Multi-Application payloads.

An overall analysis has been prepared for computer-supported requirements including consideration of reflights, and capabilities for the candidate Lead Centers. As shown in Table 2-3, only ARC and LaRC need additional software capability to do flight planning for their payloads. From information gathered during this study and during the STS Payload Mission Control Study, it is apparent that a great deal of applicable software is available.

For the heaviest indicated computer-workloads, at MSFC and GSFC, the indicated requirements are only about one hour per day. Both MSFC and GSFC operate extensive institutional computer complexes and are judged capable of assimilating the indicated workload.

In summary, computer hardware and software exist within NASA to support 10-12 Spacelab flights per year, assuming software support to ARC and LaRC by other Centers.

2.1.4 Use Payload and Mission Specialists in Flight Planning

Payload and mission specialists will be intimately involved with PI's and equipment designers. They will also participate in testing experiment equipment. Their participation in payload flight planning

Table 2-3. Flight Planning Capabilities of Potential Lead Centers

- TM-3 10-12 FLIGHT/YEAR
- INSTITUTIONAL CAPABILITIES

	CAPABILITIES		REQUIREMENTS			ASSESSMENT
FACILITY	HARDWARE	SOFTWARE	PAYLOAD DISCIPLINES	PROBABLE MAXIMUM FLTS/YEAR	COMPUTER WORK LOAD HOURS/YEAR	
ARC	IBM 360 (2) CDC 7600	INCOMPLETE	LIFE SCIENCE ASTRONOMY	2	120	WORK LOAD LIGHT POSSIBLE CONVERSION ORUSE OF NASA RESOURCES
MSFC	UNIVAC 1100'S (3)	ADEQUATE	SPACE PROCESSING AMPS MULTI-USER MULTI-APPL	4	340	CAPABILITY EXISTS WORK LOAD NOT EXCESSIVE
GSFC	IBM 360(3)	PROBABLY ADEQUATE	SOLAR PHYSICS HI-ENERGY PHYSICS ASTRONOMY MULTI-APPL	4	350	LIMITED SCHEDULING S/W WORK LOAD NOT EXCESSIVE
LARC	CDC 6000 (5)	MANNED PROGRAMS MARGINAL	ATL	1	95	SOFTWARE UPDATES REQUIRED WORK LOAD LIGHT
JSC	UNIVAC 1100's (5)	ADEQUATE	LIFE SCIENCE MULTI-APPL	2	120	WORK LOAD LIGHT CAPABILITY EXISTS

therefore offers definite advantages. In addition to reducing the Lead Center's manpower requirements, the use of Payload and Mission Specialists for flight planning improves their understanding of mission objectives. Most important, the preparation of experiment timelines and procedures by the people who will implement them on-orbit enhances the chances for a successful flight.

A typical crew training schedule is shown in the top section of Figure 2-4 and the flight planning activities for the payload are shown in the lower section of the figure. A comparison of the schedules and the activities being performed indicates that it is both possible and desirable to use payload and mission specialists to perform significant portions of the payload flight plan. For example, Block B (procedural training on experiments) and Block 5 (experiment procedures) occur in parallel and should really be performed together, i.e., experiment procedures must be written in order to do the procedural training, and their use in training will show what changes are needed to make them realistic. Also,

TRAINING SEQUENCE

Ⓐ SCREENING, ORIENTATION AND SYSTEM FAMILIARIZATION

Ⓑ PROCEDURAL TRAINING ON EXPERIMENTS

Ⓒ EXPERIMENT/SPACELAB INTERFACE TRAINING

Ⓓ COMBINED EXPERIMENTS TRAINING

Ⓔ HABITABILITY AND SAFETY TRAINING

Ⓕ INTEGRATED OPERATIONS TRAINING

Ⓖ STS/SPACELAB SYSTEMS O&M TRAINING

PLANNING SEQUENCE

① ORBIT SELECTION

② EXPERIMENT TIMELINES

③ ATTITUDE AND POINTING

④ CONSUMABLES

⑤ EXPERIMENT PROCEDURES

⑥ FLIGHT DATA FILE

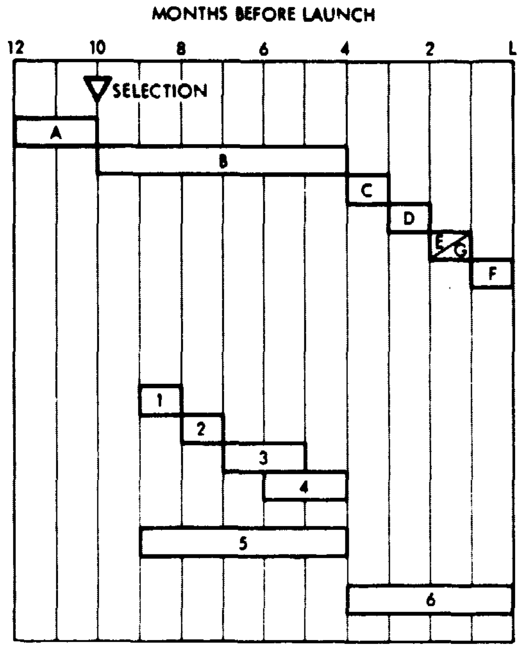


Figure 2-4. The Payload Flight Crew Can Participate in Flight Planning

orbit selection, experiment timelines, attitude and pointing, and consumables analyses can impact the procedures for operating the experiments and should be considered during procedural training on experiments; accordingly, Blocks 1, 2, 3, 4 are deemed logical activities for the payload and mission specialists during their training on experiment procedures.

Analysis of the training load for the payload and mission specialists indicates that time will be available for payload flight planning up to 4 months prior to launch. The likelihood that backup crew members will be assigned and trained increases the amount of specialist's time that can be applied to the flight planning activity. Accordingly, it is recommended that the specialists be used to help develop the payload flight plan during their training on experiment procedures at the host center, the experiment contractor's facility, or at the Principal Investigator's laboratory.

2.1.5 Summary and Recommendations

The four manpower reduction factors, the rationale for their selection and the advantages are summarized in Table 2-4. Based on the analysis performed during the CRAS study it is recommended that NASA adopt decentralized flight planning at each payload lead center and consider the combination of some aspects of flight planning and flight crew training.

Table 2-4. Evaluation of Manpower Reduction Factors

COST/MANPOWER REDUCTION FACTORS	RATIONALE	ADVANTAGES
MINIMIZE CONTINGENCY/ MALFUNCTION PLANNING	• MOST CONTINGENCIES SOLVED BY CHANGES TO TIMELINE • SCIENCE/EQUIPMENT MUST BE EVALUATED IN REAL TIME	• REDUCES TOTAL MANPOWER
MINIMIZE FLIGHT PLANNING ITERATIONS	• DEVELOP FLIGHT PLANS ONLY WHEN REQUIRED TO SUPPORT PAYLOAD OPERATIONS PLANNING OR DESIGN • REPLAN ONLY WHEN HARD TEST DATA BECOME AVAILABLE	• REDUCES TOTAL MANPOWER • ALLOWS USE OF PLANNERS FOR OTHER SYSTEMS ANALYSIS ACTIVITIES DURING HARDWARE DEVELOPMENT • REDUCES COMPUTER USAGE
MAXIMIZE USE OF EXISTING NASA COMPUTER RESOURCES	• COMPUTATIONAL WORKLOAD AT POTENTIAL LEAD CENTERS IS WITHIN CAPABILITY FOR 10 FLIGHTS/YEAR MODEL • SOFTWARE FOR PAYLOAD FLIGHT PLANNING GENERALLY EXISTS WITH NASA	• REDUCE NEW HARDWARE EXPENDITURES • REDUCE SOFTWARE CONVERSION/DEVELOPMENT • AVOID LEARNING COSTS OF NEW SYSTEMS
MAXIMIZE COMMON USE OF MANPOWER	• CREW TRAINING AND FLIGHT PLANNING ARE CLOSELY RELATED • PAYLOAD FLIGHT CREW CAN PARTICIPATE IN FLIGHT PLANNING • TRAINING AND PLANNING SEQUENCES ARE SYNCHRONIZED	• REDUCES LEAD CENTER MANPOWER REQUIREMENTS • MAXIMIZES USE OF HIGHLY QUALIFIED PEOPLE • ENHANCES CONTINUITY FROM FLIGHT PLANNING THROUGH OPERATIONS

2.2 SPACELAB PAYLOAD OPERATIONS CENTER REQUIREMENTS

The objective of this study was to estimate the equipment, facilities and manpower required for a minimum Payload Operations Center (POC). The estimates were to be developed for each of the reference payload disciplines and for each of the traffic models. In order to accomplish these objectives the following tasks were accomplished:

1) Requirements Definition
2) Equipment Estimates
3) Requirements by Traffic Model
4) Manpower Estimates.

2.2.1 Requirements Definition

An analysis was made of eight discipline payloads and of the first and second Spacelab missions, as they are defined in the DRM's and Level A and B sheets that were issued in the spring and summer of 1975. This analysis established the requirements that each payload would have for each of the planning functions defined below:

- Maneuvering
- Pointing
- Time Dependencies
- Orbital Position Relationships
- Restrictions on Orbiter Operations
- Special Communications
- Order of Experiment Performance.

2.2.1.1 Console Requirements

Based on the planning requirements established, a number of information displays and communication situations were postulated. These flight planning aids were developed so that a necessary and complete set of aids could be defined for each discipline.

The information displays are broken down into:

- Those that are of a dynamic nature and so would require computer assistance in their formulation either for formatting of data or computation of data products
- Those that become fixed when the actual orbit has been achieved, such as ground track, or those that are supplied by external agencies, such as weather prediction.

In order to develop equipment requirements for the Payload Operations Control Center (POCC), as they relate to the amount of planning and operational autonomy allowed to the crew, three levels of autonomy were defined.

1) Assistance Only. Full autonomy is allowed the crew except that the POCC must be ready to assist in diagnosis of malfunctions and in recommending remedial measures either through repair or through changes in procedures and plans.

2) Minimum Command. This level provides the minimum amount of equipment necessary for the POC to command instruments when the crew is not available. It also allows the POCC to develop daily activity plans for recommendation to the crew.

3) Full Control. This level provides adequate equipment for the POCC to do all the planning and instrument commanding. It does not provide for a console dedicated to each instrument in those cases where all instruments will not be operated simultaneously.

Discussions were held with key personnel in NASA Headquarters experiment sponsoring offices and with knowledgeable Field Center personnel regarding the attitudes of current Principal Investigators toward autonomy to the flight crews. The results of these discussions were reinforced by examination of the planned experiment designs as evidenced in the Level A and B sheets.

It is recognized that individual investigators may differ from these community attitudes. Additionally, there is reason to believe that community attitudes will change as experience is gained in Spacelab operations. However, the present P. I. communities do have dominant attitudes and they differ from discipline to discipline.

The information and communication requirements, the crew autonomy alternatives and the attitude of Principal Investigators were combined to develop the most probable combinations of displays, command and communication positions required for each reference discipline. These most likely configurations are shown, by cross hatch, in Table 2-5.

Table 2-5. Most Likely Console Configurations

	COMBINED ASTRONOMY			LIFE SCIENCES			MULTI-APPLICATIONS			AMPS			ATL			FIRST MISSION		
	1	2	3															
CRT DISPLAY POSITIONS																		
MCC PROVIDED DATA	2	2	3	2	2	3	2	2	3	2	2	3	2	2	3	2	2	3
POC PROVIDED DATA	2	4	5	2	2	4	1	3	6	2	6	12	1	3	7	2	2	4
TOTAL	4	6	8	4	4	7	3	5	9	4	8	15	3	5	10	4	4	7
DAILY DISPLAYS		1			1			3			3			2			2	
ONE-TIME DISPLAYS		2			0			0			2			1			3	
COMMAND POSITIONS	0	1	4		0			0		0	1	6		0			0	
SPECIAL COMMUNICATIONS		-			-			GROUND TRUTH OPERATIONS			GROUND OBSERVERS			GROUND TRUTH OPERATIONS				

1 POC ASSISTANCE MODE 2 MINIMUM POC COMMAND MODE 3 FULL POC CONTROL MODE

2.2.1.2 Data Handling Requirements

In order to determine the data handling requirements of the POC, the instrument complements of the reference missions were examined. The projected data rates for both experiment housekeeping data and scientific data are summarized below.

1) The nominal maximum data rate that can be transferred through NASCOM in circuits is 1.344 megabits per second. Presently this rate applies to data transmission from the STADAN network or from the TDRSS terminal. Although there are discussions about ways to increase this transmission from the TDRSS terminal through a Domestic satellite link directly to JSC.

2) All payloads that were studied have total science and housekeeping data rates well below 1.344 mbps with the exception of AMPS (2.7 mbps) and Solar Physics (1.32 mbps).

3) Although there are a number of instruments that generate data at very high rates, there is no practical way to present these data in realtime so that their totality can be considered by the investigators. Moreover, examination of the instruments and the type of data to be produced indicates that none of the projected investigations are concerned with statistical aspects of the high rate data.

4) In order to present high rate data to the investigators in the POCC, it will be necessary to either bring the data stream to the POC for appropriate sampling or perform this action onboard the spacecraft. Onboard sampling can reduce the rate so that it can be easily handled by existing communication equipment. In contrast, data rates in the range of tens of megabits per second have been discussed. Several elements of the communications network will require technological development work to assure accurate operation at these rates.

2.2.2 Equipment Estimates

In order to minimize the hardware (and software) in a POC it is necessary to limit the functions that it will perform. If an attempt is made to satisfy all stated and implied requirements a very sophisticated system would evolve.

The basic job of the POC is to present sufficient data to payload personnel so that they can assist in optimizing the scientific observations. Except for the commanding of instruments, little can be done by the POC

in real time. Most of the decisions in the POC will have a time scale on the order of hours as contrasted to the short time scale of safety related decisions. This aspect, in relieving much POC equipment from the necessity of having to operate in real time, effects a considerable simplification in the computational and display components. In order to accomplish these tasks the following functional equipments are required.

- Front End Processor

  Function: Bit sync, decommutate, position and time correlate data route to storage

  Capability: Pre-Domsat, up to NASCOM line data rate (1.34 mbps);with-Domsat, as required by science (2 to 3 mbps).

- Data Storage

  Function: Hold data for access by POC computer system

  Capability: Tape major portions of data stream; quick access (disk) storage of working data (1 to 2 M bytes).

- Computer System

  Function: Access data from POC storage and from MCC, develop displays, simple scientific calculations, generate command loads, interrupt/prioritize.

  Capability: Not real time, Fortran compatible, access from three sources, interrogated by up to 10 peripherals.

- Consoles

  Function: Request and display data, transfer commands

  Capability: No software, alpha/numeric-display/entry, graphics, symbol generator, display refreshment, partial display update.

It is assumed that: (a) payload PCM data will be routed to the POC by the MCC directly as received, (b) any payload data that is interleaved with Orbiter instrumentation data will be stored in the MCC data base and is accessible by the POC computer, and (c) the POC can directly access Orbiter and Spacelab systems data and trajectory information in MCC format. Based on these assumptions and the equipment requirements a generalized POC schematic was developed as shown in Figure 2-5.

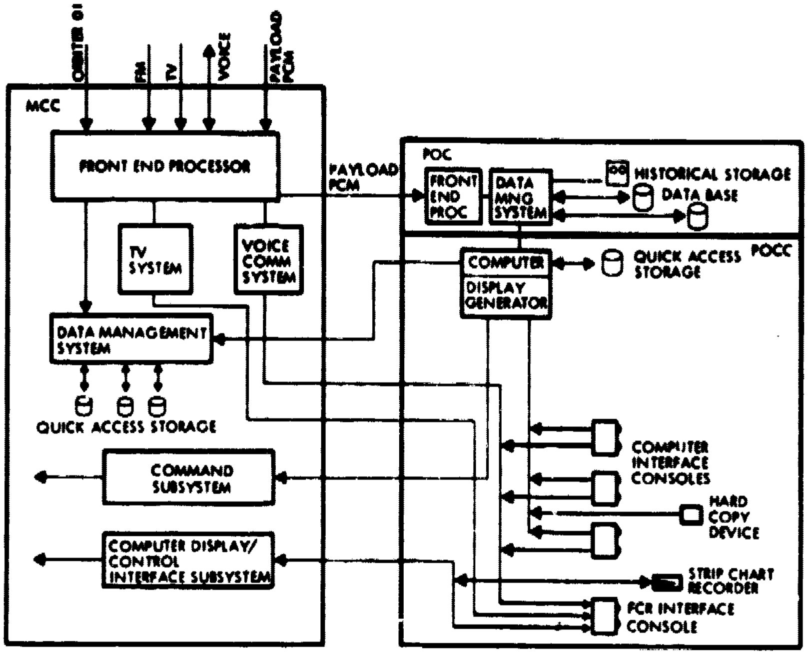


Figure 2-5. Generalized POC Schematic

The POC will provide for historical storage of all payload data; for formatting and display of these data as requested by investigators; for formatting of commands to the payload; for voice communication with the Spacelab; and for display of Spacelab T. V.

The POCC consoles will be selected to interface with the POC computer and display generator. It would be advantageous if they had similar characteristics to those in the MCC so that all consoles could access Orbiter data. If this is not practical a special MCC type console will have to be provided. The number of consoles and other peripherals to be used can be adjusted, over a reasonable range, as demanded by the particular flight.

Table 2-6 below presents types of commercially available equipment that can fulfill the required functions. In some instances specific equipment is mentioned. In others a price is stated which covers a range of equipments that are considered adequate to do the job.

The equipment selection was done by TRW personnel who are actively engaged in the design of data handling systems. However, the study was performed only to the depth that would develop a general understanding of

the equipment needed to perform the functions. Actual design of a POC and sizing of the components will require an in-depth analysis of the nature of the data and its flow rates.

Table 2-6. Representative POC Equipment

FUNCTION	EQUIPMENT	ESTIMATED COST (1000)	NUMBER REQUIRED	SYSTEM COST (1000)
FRONT END PROCESSOR 1 MBS	COMM. PROCESSOR	20	1	210
	DATA MANAGER	70	1	
	100 MBYTE DISK	30	2	
	TAPE RECORDER	30	2	
FRONT END PROCESSOR 3 MBPS	PROCESSOR		1	810
	DATA MANAGER	70	1	
	LARGE DISKS		2	
	DISK CONTROLLER		1	
	TAPE RECORDER	30	2	
GENERAL PROCESSOR	PDP 11/70	70	1	70
	ECLIPSE 200			
DISPLAY GENERATOR	PDP 11/70	70	1	70
	ECLIPSE 200			
CONSOLE	RAMTEC GX100 DISPLAY COMMUNICATION	25	X	X
ANCILLARY EQUIPMENT	HARD COPY	10	1	20
	STRIP CHART RECORDER	10	1	
SUPPORT EQUIPMENT	TAPE READER CARD READER		1	30

2.2.3 Equipment Estimates by Traffic Model

A question that should always be examined is whether it is more advantageous to provide a large centralized data handling facility or a group of smaller facilities keyed to the demand.

The front end processor and data base operate for only about twelve months per year at the 29 per year rate (Traffic Model TM-1). Therefore, one set of equipment should, nominally, be able to handle the traffic. However, unless adequate ground handling facilities are provided to accommodate to variable launch timing, the occurrence of simultaneous flights is about 3 months of the year. Thus, two sets are required at higher flight rates. As there are more than two POCC's needed at these rates, it would be more economical to have this equipment centralized to service all POCC's.

The computer system could also be centralized or distributed. However, these elements together with the peripherals are used for POCC personnel training. Additionally, the major software changes from flight

to flight will be in this computational system. In a first order estimate, one could assume that the total cost for computational equipment will be about the same whether it is centralized or distributed. However, the centralized computer system must be sized, at the outset, for the maximum expected traffic. Because the ultimate traffic to be accommodated is not known at this time, and because a centralized system imposes high early costs, it is concluded that the computers should be dedicated to POCC's. Additional ones can be purchased as the traffic rate dictates.

Software is constructed on lead center institutional computers using programs that emulate the POC computer. For mature operations, when the emulation programs have been proven, it is estimated that installation and test of the software in the POC will take about one month. This time will vary with the complexity of the flight. In all cases however, the payload software will change from flight to flight and must be tested in the POC environment. It is further estimated that about two weeks should be allocated to training of the POC team and in integrated simulations with the STS flight control team. Equipment and software used in this training should be identical to those to be used during flight. It can be demonstrated that use of facilities separate from the POC for software testing and POC team training will not effect a significant overall saving in equipment.

Overall, the POC will be in use for 50 to 60 days for each seven day flight and for 75 to 85 days during a 30 day flight. This analysis assumes use of the POC's for the software and training functions and hence a 60-day turnaround for POC's (7 day flights). Each of the traffic models have specific numbers of 7-day and 30-day flights. This dictates that POC facilities are needed for a specific number of months, depending on the length of time that a POC is used. These data are shown for each traffic model in Figure 2-6.

Figure 2-6 shows that the maximum rate traffic model (TM-1), in 1991 requires 64 months of POC occupancy. This would call for one more POC than the 5 listed. Because no attempt has been made to determine the relationship between turnaround time and flight discipline, this is considered within the precision of the study.

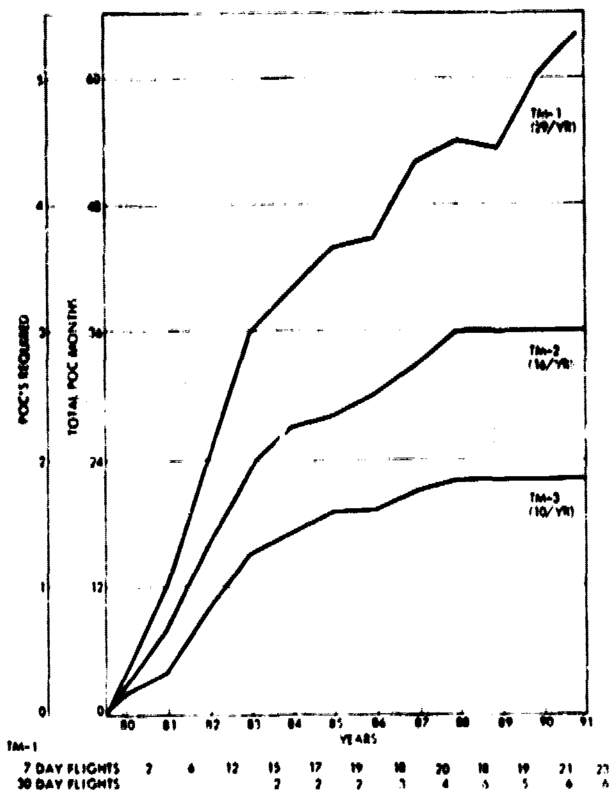


Figure 2-6. Spacelab Ground Facility Requirements

The total number of each type of POC equipment was estimated by year as a function of the traffic models. This is based on the previously determined numbers of POC's needed and partially on the equipment requirements of the most likely POCC's and is shown in Table 2-7.

In analyzing the most likely POCC's, it can be seen that only one discipline (Life Sciences) would use the minimum sized POCC. Because of this, all POCC's were considered to be either Minimum Command size or Full Control size. The latter was used for all astronomy, hi-energy physics, and solar physics payloads. Because there is a difference in the number of consoles needed between disciplines for either size of POCC, the number used was 7 for Minimum Command and 9 for Full Control. This should be conservative enough to provide sufficient peripheral equipment so that POCC's can be tailored to the specific requirements of each flight.

Table 2-8 shows the total cost for POC equipment for the three traffic models through 1991. This chart demonstrates the sensitivity of total costs to the cost of the Front End Processor. Three instances are shown:

1) With the JSC MCC providing front end processing and data storage for the POC, no attempt was made to estimate the cost of augmenting the MCC to provide this service.

2) With a ≈1 megabit per second front end in the POC.

3) With a 2 to 3 megabit per second front end in the POC.

Table 2-7. Total POC Equipment Requirements

• BASED ON 60 DAY POCC TURN AROUND AND MOST LIKELY POCC'S

	CY	80	81	82	83	84	85	86	87	88	89	90	91
	FRONT END AND DATA BASE												
①	TM-1	2			4								4
	TM-2	2				4							4
	TM-3	2											2
	ANICLLARY EQUIPMENT												
②	TM-1	1		2	3	4			5				5
	TM-2	1		2		3							3
	TM-3	1			2								2
	OPERATOR CONSOLES												
③	TM-1	9		16	25	32			39				39
	TM-2	9		16		25							25
	TM-3	9			16								16
	POCC COMPUTERS												
	TM-1	2		4	6	8			10				10
	TM-2	2		4		6							6
	TM-3	2			4								4

① REDUNDANT SETS - ALSO INCLUDES SOFTWARE INSTALLATION AND TEST EQUIPMENT
② HARD COPY DEVICE, STRIP CHART RECORDER
③ ASSUMING SIMILAR CONSOLES TO THOSE IN THE FCR'S

Table 2-8. Total PCC Equipment Costs - Thru 1991 (Dollars in Millions)

TRAFFIC MODEL	MAX. NOS.	MCC PROVIDED FRONT END AND DATA BASE	POC PROVIDED ~1 MBPS FRONT END	POC PROVIDED ~3 MBPS FRONT END
TM - 1	(29)	1.8	2.7	5.1
TM - 2	(16)	1.2	2.0	4.4
TML -3	(10)	0.8	1.2	2.4

No attempt was made to develop costs for a front end processor that would operate at higher data rates because it is believed that this will require new technology development.

2.2.4 Manpower Estimates

The manpower estimates developed in this study are based on an assessment of the manpower required to develop POC software and the number of people required to be assigned to the POC for payload operations.

2.2.4.1 POC Software Development, Test and Integration Manpower Estimates

Manpower estimates to develop, test and integrate software to support experiment operations in the POC are based on experience and a

understanding of the functions to be performed. The software requirements will vary from discipline to discipline and a much more detailed study would be required to make a more accurate estimate. Program word size estimates were made based on similar existing programs; these were then converted to instructions by an average of 30 words per instruction. Manmonths were then estimated using approximatley $31/instruction and $50,000 per man year as the conversion factors. The estimates for system specification and integration were based on the proportion of these efforts to total manpower from past software programs. For program conversion a "rule of thumb" of 1/4 the manpower of new code was used. These data are summarized in Table 2-9.

Table 2-9. POC Software Development, Test and Integration Manpower Estimates

SOFTWARE PROGRAM	SIZE		FIRST FLIGHT MANMONTHS	REFLIGHT MANMONTHS
	WORDS	INSTRUCTIONS		
SYSTEM SPECIFICATION	-	-	9	-
OPERATING SYSTEM	-	-	18	-
DATA STORAGE AND RETRIEVAL	100K	3.3K	24	-
DISPLAY GENERATOR • 40 FORMATS	100K	3.3K	24	3
DATA BASE STRUCTURING	-	-	18	9
MATH MODEL CONVERSION • AVG & EXPERIMENT SYSTEMS	(200K) 50K	1.7K	12	12
SPECIAL PLANNING PROGRAMS CONVERSION	-	-	6	6
INTEGRATION AND TEST	-	-	42	12
TOTAL SOFTWARE DEVELOPMENT			153	42

2.2.4.2 POC Manning, for Training and Operations

In order to develop estimates of manpower requirements for the POC a baseline scenario was generated. It is estimated that about three weeks would be required for indoctrination and training so that the POCC team would be capable of operating effectively with the STS Operator and Crew in integrated simulations. This means that about 3-1/2 weeks would be required preflight, as shown in Figure 2-7.

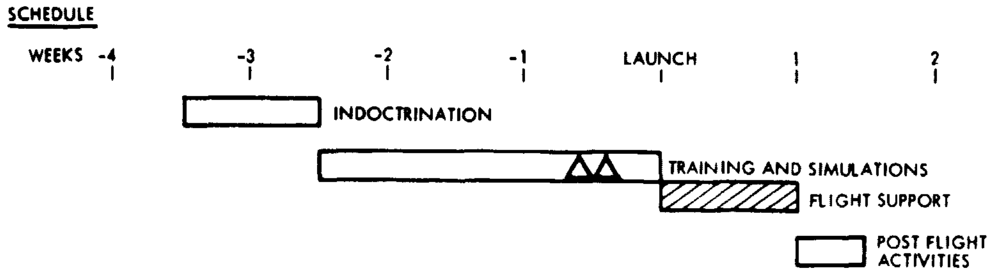


Figure 2-7. Baseline POC Manning Scenario

At least a half-week post flight should be provided for POC participants to investigate the nature of the recorded data and to establish with the MCC the type of Orbiter and Spacelab data needed for the scientific analyses. Thus, the participants are expected to be in residence 5 weeks for a 7-day flight and 8 weeks for a 30-day flight.

The payload manager should be in residence and have primary responsibility for payload operations. Based on Apollo and Skylab experience, there should be a chief scientist who has responsibility for making decisions between investigators where there are conflicting demands on flight resources. He should be available for each days' activities planning and for preplanning strategy sessions. This could take as much as 16 hours each day. There should be a payload flight planner in charge of each shift. Experiment development engineers and investigators should be operating in the POC on all shifts. The number of these depends on the number required by the payload. For this analysis the numbers are matched to the number of consoles provided in the most likely POCC's.

Total numbers of personnel in-residence are shown in Table 2-10 as a function of the POCC autonomy alternative. The equipment support personnel are required only for payload unique equipment. The operations and maintenance of other POC equipment can be best supplied by MCC personnel.

Table 2-10. POC Manning, Training and Operations

	NO. NEEDED			SHIFTS	TOTAL NO. PEOPLE		
	AO	MC	FC		AO	MC	FC
PAYLOAD MANAGER	1	1	1	1	1	1	1
CHIEF SCIENTIST	1	1	1	2	2	2	2
PAYLOAD FLIGHT PLANNER	1	1	1	3	3	3	3
EXP DEVELOPMENT ENGINEER	1	3	4	3	3	9	12
PRINCIPAL INVESTIGATOR	1	3	4	3	3	9	12
EQUIPMENT SUPPORT	1	4	5	1	1	4	5
					13	28	35

AO = ASSISTANCE ONLY
MC = MINIMUM COMMAND
FC = FULL CONTROL

Using the previous scenario it is estimated that POCC manning should be about 28 for a Minimum Control POCC and 35

for a Full Control POCC. They should be in residence for about 5 weeks for a 7-day flight and about 8 weeks for a 30-day flight.

With the most likely POC's proscribed, the manpower requirement averaged across each traffic model is about 40 manmonths per flight.

2.2.4.3 Lead Center POC Manpower Estimates

Based on the previously presented data, an estimate of the total equivalent manpower needs of each of the potential lead centers was made. This is shown in Table 2-11 in man years by lead center and traffic model.

Table 2-11. Manpower Estimates by Discipline and Traffic Model

OPERATIONS
- MANNING 28-35
- DURATION 5-8 WEEKS
- AVERAGE 40 MAN MONTHS

SOFTWARE
- 153 MAN MONTHS FIRST FLIGHT
- 42 MAN MONTHS REFLIGHT

TRAFFIC MODEL	MANPOWER ESTIMATES IN MAN YEARS									
	MSFC		GSFC		LaRC		JSC		ARC	
	S/D	OPS	S/D	OPS	S/D	OPS	S/D	OPS	S/D	OPS
TM-1 (29)	290	265	185	165	132	120	73	60	69	55
TM-2 (16)	163	145	128	110	65	55	55	45	51	40
TM-3 (10)	107	90	100	85	41	30	41	30	34	20

S/D - POC SOFTWARE DEVELOPMENT, INTEGRATION AND TEST
OPS - POC OPERATIONS

2.2.5 Summary and Recommendations

The equipment, manpower and facilities required for a minimum POC were evaluated and assessed. The following points summarize the study results:

1) A modular POC, based on the use of mini/micro processors, can support payload operation for an estimated cost from 400 thousand to 2 million dollars each.

2) The cost of the POC varies mainly because of alternatives in the processing of science data:

Science Data Rate	POC Cost
<128 kbps	≈$ 400K each
<1 mbps	≈$ 800K each
<3 mbps	≈$2000K each

3) Manpower estimates for POC software development and operations average 80 to 100 man months per flight; POC software (40 to 60) and POC operation (40).

4) As many as five POC facilities are required to provide reconfiguration, training and real time support.

Based on these results it is recommended that the NASA plan for a modular POC based on the use of mini/micro processors and review the real need for high rate science data in the POC. Additionally, means to reduce the manpower requirements should be studied such as standardized software units and the use of firmware in place of software.

2.3 EXPERIMENT DATA PREPROCESSING ALTERNATIVES

The objective of this study was to analyze the alternative approaches to experiment data preprocessing. Alternatives were developed based on the requirements of each payload, the communication links available and equipment and software required for ground preprocessing.

There are two objectives of the data preprocessing function: to provide high quality data tapes which can be reduced and analyzed by the user, and to provide a limited amount of data for real time or near real time data display. The activities required to prepare the data for analysis and interpretation are performed and paid for by the user and are not a part of this study.

The functions described below are those activities which are required to provide the user with high quality, computer compatible digital tapes ready for processing and analysis. The data is to be calibrated and grouped in blocks of science data by experiment.

- Create time continuous, non-redundant computer compatible data files
- Telemetry data reduction
- Perform data quality control and flag questionable data
    - Verify frame sync
    - Time correction/correlation
    - Event status
    - Reference voltage verification
    - Transmission error detection

- Group data into functional blocks
  - Calibration
  - Science data by experiment
- Provide selected data for quick look display.

2.3.1 Requirements

Several questions need to be discussed with respect to 50 mbps real time data. That much data is clearly much more than could be evaluated during the flight. If this is true, then where does the requirement come from? Our review of the data generated by the DRM experiments and other missions indicates that there are several imaging type sensors which generate 50 mbps or more. The DRM's indicate that these data will be stored onboard. The real time experiment data rate requirements established by the DRM's are shown in Figure 2-8.

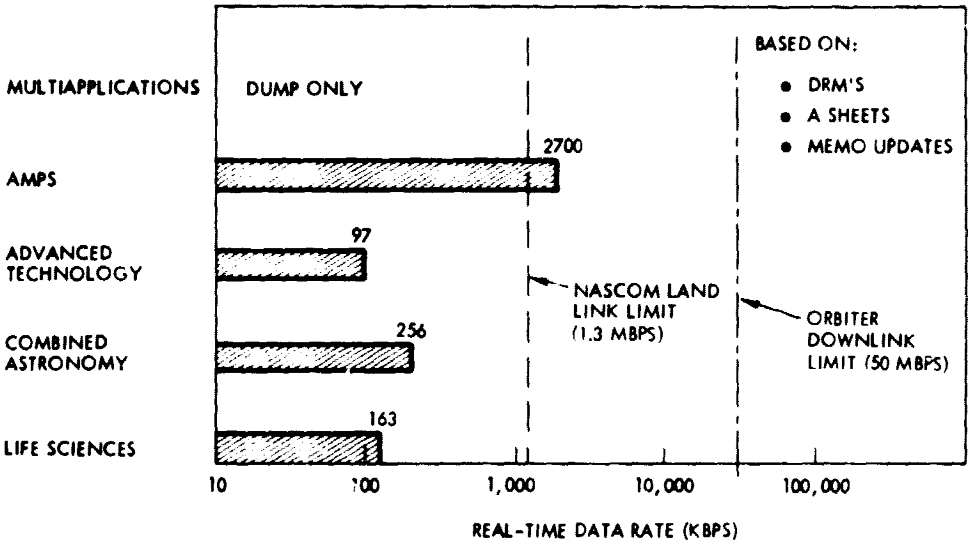


Figure 2-8. Real Time Experiment Data Requirements

However, for the purpose of this study it has been assumed that the 50 mbps real time data is required. There are several advantages of real time data transmission. The data is available on the ground for real time decision making and there is no need to record onboard in expensive flight qualified recorders. There are disadvantages, too. A network of satellites and land lines is required to send the data to the processing site. This

could include TDRSS, DOMSAT, receiving stations for each system, and microwave links between centers. Additionally, to process the data in real time some technology advancement would be required.

2.3.2 Data Communications Link Alternatives

The communication links available to Spacelab payloads in the operational era have not been defined. There is the possibility of the use of the Tracking and Data Relay Satellite (TDRS) and the Domestic Satellite (DOMSAT) systems for relaying data to the ground for preprocessing. An overview of these possible alternatives is shown in Figure 2-9.

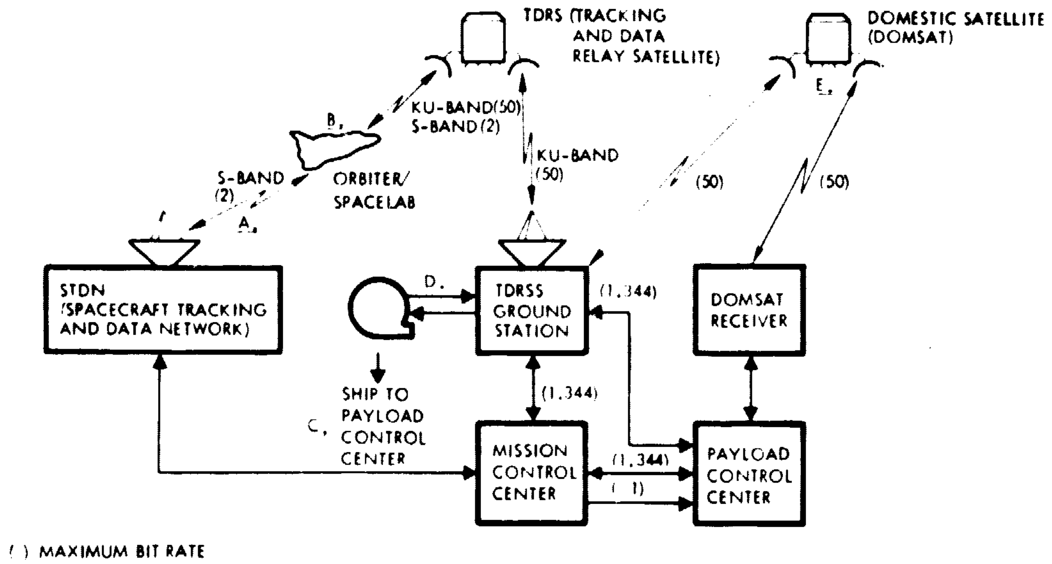


Figure 2-9. Data Communications Link Alternatives

As shown in the figure, the following alternatives are available within the planned NASCOM system, to transmit and distribute the experiment data from Spacelab.

- Orbiter operational instrumentation link ~≤ 2 mbps
- Record onboard Orbiter - bringdown or playback ~400 to 500 mbps
- T/M via TDRS - record and ship tapes ~50 mbps
- T/M via TDRSS - record then playback through landlines ~≤1.344 mbps
- T/M via TDRSS/DOMSAT directly to center(s) ~<50 mbps.

The advantages and disadvantages of each of these options is summarized below.

COMMUNICATIONS LINKS	ADVANTAGES	DISADVANTAGES
• ORBITER OI LINK	• LOW COST • EQUIPMENT AVAILABLE AT MCC AND ONBOARD • REAL TIME DATA	• SPECIAL DATA HANDLING AT EXPERIMENT • LIMITED TO 2 MBPS
• RECORD ON-BOARD	• NO COST TO S/L	• NO REAL TIME DATA • WEIGHT IN ORBIT • FLIGHT QUALIFIED RECORDERS • NO QUICK LOOK DATA • LIMITED AMOUNT OF DATA • FREQUENT CHANGING OF TAPES
• RECORD AT TDRSS GROUND STATION	• ONLY GROUND RECORDER NEEDED • NO ONBOARD IMPACT	• NO REAL TIME DATA • NO QUICK LOOK DATA
• PLAY BACK THRU LAND LINES	• QUICK LOOK DATA • JSC, GODDARD LAND LINES EXIST	• COST OF ADDITIONAL LAND LINES • LIMITED TO 1.344 MBPS • COMPLICATES GROUND STATION OPERATION
• DOMSAT RELAY	• REAL TIME DATA • MULTIPLE SITE RECEPTION	• COST OF DOMSAT RECEIVERS • DOMSAT RENTAL

2.3.3 Data Preprocessing and Quick-Look Alternatives

A concept of the preprocessing system including the front end processor, i.e., the interface between the telemetry receiver and the preprocessing computer and the computer system is shown in Figure 2-10.

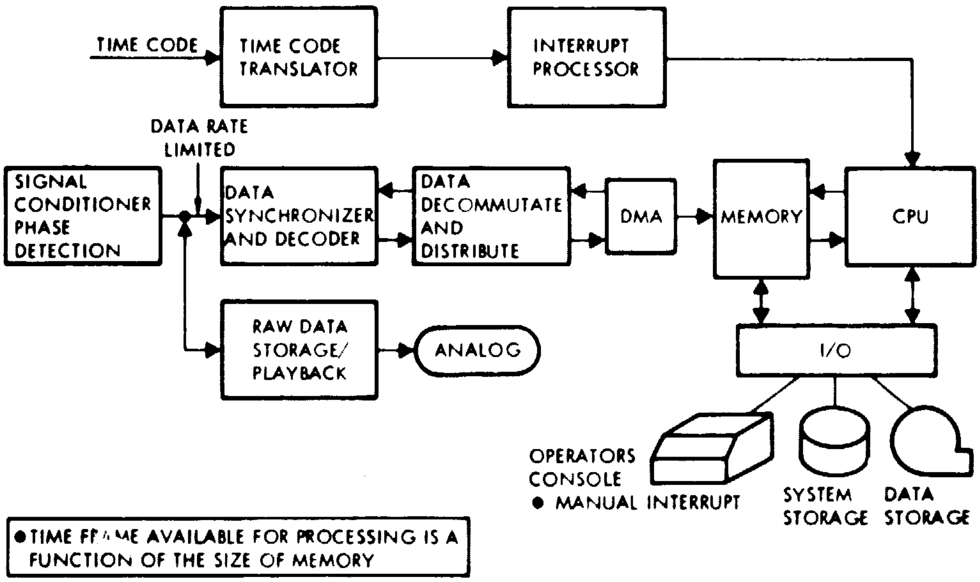
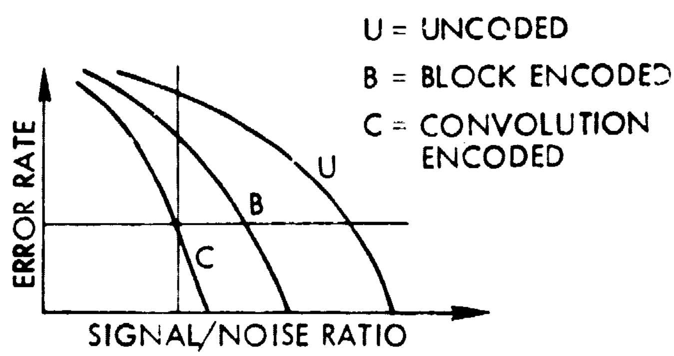


Figure 2-10. Function Description of the Data Preprocessing System

Experiment digital data that has been put on the high rate data link is signal conditioned and phase detected. The data is then bit synchronized (or symbol synchronized, if encoded), decoded (if previously encoded), and frame synchronized. The frame synchronized digital data is then decommutated, serial-to-parallel converted, and interfaced with the pre-processing system computer for calibration, editing and quality control, regrouping, and the creation of computer compatible data files or tapes. Recording of the raw digital data for storage and subsequent playback would take place before the data has been converted to a digital bit stream by the bit (or symbol) synchronizer.

High data rate limitations occur in the data synchronization/decoding process. Synchronization hardware has been demonstrated at high bit rates; however, there is an increase in the bit error rate. In order to achieve the high fidelity bit signal required for Spacelab, error correction coding is necessary.

Convolution encoding and decoding becomes necessary when, with the available RF power and antenna systems, it becomes impossible to obtain a signal-to-noise ratio high enough to give an acceptable bit error rate.



Current technology can provide bit/symbol synchronizers up to 5 mbps, and are projected to operate at 50 mbps in the Spacelab time period.

Convolution decoders are currently being developed which can work at up to 5 mbps, and in the time frame of Spacelab, should be available to work in the 10 to 15 mbps range. NASA is expected to conduct studies to advance this technology for STS applications in the near future. In order to handle higher data rates, the data stream must be split and the decoders employed in parallel. Figure 2-11 depicts the "parallel" concept being considered to implement the handling of high telemetry data rates beyond the capability of anticipated decoding equipment.

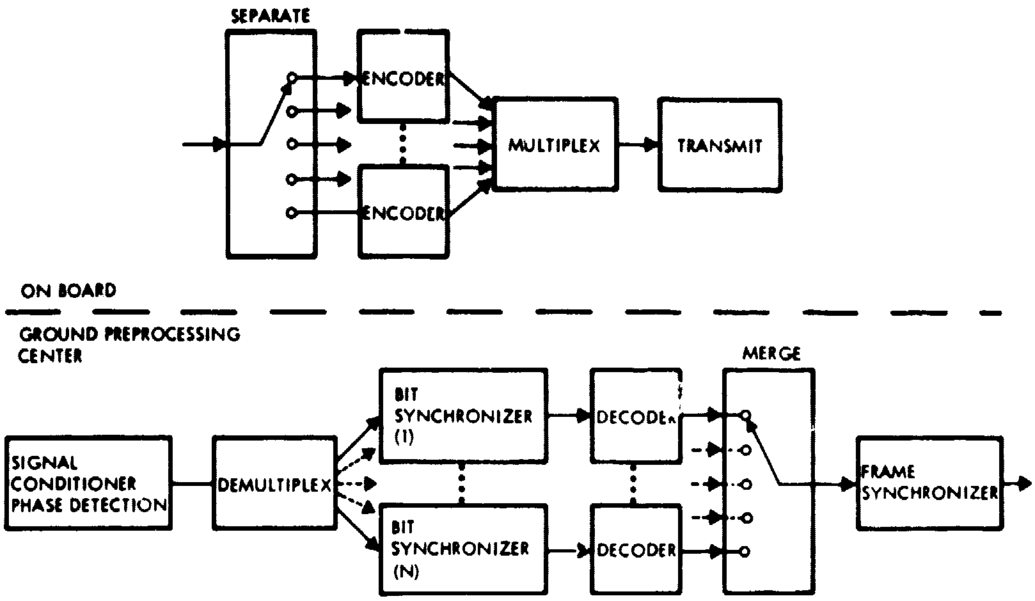


Figure 2-11. Anticipated Approach to Processing Data Rates Greater than 10 to 15 MBPS

Basically, this process would separate the high-rate digital data stream in the Orbiter into a number of lower rate data streams; each of these lower rate data streams would be capable of being handled by encoding/decoding equipment. Each of these lower rate data streams would be separately encoded in the Orbiter and then multiplexed together for transmission to the ground. On the ground, the multiplexed signal would be demultiplexed into the component signal streams and each of these component signal streams would then be individually bit/symbol synchronized, decoded, and then merged back together to form the total high data rate bit stream, which is then available for frame synchronization and subsequent preprocessing steps.

The pros and cons of the preprocessing alternatives are shown below.

PREPROCESSING	ADVANTAGES	DISADVANTAGES
• REAL TIME AT PAYLOAD CENTER	• DATA AVAILABLE FOR PROCESSING AND DISPLAY IN NEAR REAL TIME	• STATE OF THE ART EQUIPMENT REQUIRED
• STORE AND PLAYBACK	• AVAILABLE EQUIPMENT IS ADEQUATE	• NOT AVAILABLE IN REAL-TIME

There appears to be no advantage to real time preprocessing of the high rate data. Additionally, the capability to perform real time, high data rate preprocessing requires an advancement in the technology for front-end processing. The data can be stored and played back at slower rates and preprocessed on existing equipment. To provide data for scientific evaluation in the payload operations center three alternatives appear possible, the advantages and disadvantages of these options are summarized as follows.

QUICK LOOK	ADVANTAGES	DISADVANTAGES
• REAL TIME SNAPSHOT OF 50 MB DATA	• DATA AVAILABLE IN REAL TIME	• REAL TIME DATA ACCESS • DATA MUST BE IDENTIFIED AND SEPARATED FOR DISPLAY
• STORE AND PLAYBACK OF 50 MB DATA	• AVAILABLE EQUIP. • DATA AVAILABLE ~ 4 HRS	• DATA MUST BE IDENTIFIED AND SEPARATED FOR DISPLAY
• USE OF REAL TIME INSTRUMENTATION LINK	• REAL TIME DATA • AVAILABLE EQUIP. AT MCC	• EXPERIMENT EQUIPMENT MUST SEND DATA TO BOTH K BAND AND OPERATIONAL INSTRUMENTATION

Quick look information can be inexpensively obtained by placing all payload data for real time display on the Orbiter operational instrumentation link.

2.3.4 Study Results and Recommendations

The real time preprocessing of 50 mbps does not appear to be required:

- Maximum DRM real-time data rate only 2.7 mbps
- 50 mbps provides too much data to be evaluated in real-time
- High data rate sensors/missions plan to record their data
- Ground versus on-board data recording tradeoffs need to be considered.

The preprocessing of experiment data should be accomplished by recording the data as it is transmitted and playing the data back at low speed to minimize costs.

- Lower cost data communications
- Simpler, cheaper telemetry data handling

- Less need for special purpose or dedicated preprocessing computer hardware
- Increased ability to use currently available equipment.

Data that is required to evaluate the performance of the instruments, both scientific and housekeeping, should be downlinked on the Orbiter instrumentation link (~2 mbps), processed in the MCC and routed to the POC for display.

- Capability will exist at MCC after OFT
- Current equipment is adequate.

3. FLIGHT CREW TRAINING

The general objective of this task is to define and evaluate logical alternative approaches to Spacelab flight crew payload associated training which, when compared to the SBPP, reduce the investment in supporting facilities, hardware and software and training personnel, but do not compromise safety or system performance.

Following the mid-term briefing TRW was directed to perform the following activities in addition to those defined in the NASA Statement of Work for this task.

1) Update the Spacelab design baseline and examine the impact of remote control upon the operations task analysis.

2) Examine the pros and cons of using the Hi-Fi Mockup, the Engineering Model and Concept Verification Test/General Purpose Laboratory Simulator (CVT/GPLS) in the training of the flight crew and payload and mission specialists.

3) Examine the possibility of incorporating flight crew and payload and mission specialist training into levels II and III Shuttle/Spacelab/Payload integration.

4) Based upon the results of the revised task analysis and the applicability of the following planned for equipments, re-examine the need for the \$6.0M Spacelab simulator.

The following material describes the processes employed and products generated to accomplish the task objectives and special study requirements.

3.1 CREW TRAINING TASK ANALYSIS/REQUIREMENTS DEFINITION

In order to define cost effective approaches to Spacelab flight crew training, it is first necessary to define the training requirements. A systems approach was used in performing the analyses necessary to define these requirements. This systems approach consisted of the following steps.

It first entailed an analysis of the Spacelab design in order to define the function, operation and performance capabilities of the equipment. Next, an analysis was performed to identify the following:

- Manned operations and interactions with the equipment
- Time and performance criticality of manned operations
- Skills and knowledge levels required to perform the tasks
- Types of training equipment required to develop requisite skills and knowledge.

Once the manned operations requirements are defined and documented, the training objectives for each manned position are collated and a training program and training sequence developed which ensures the systematic and timely development of required skills and knowledge in the personnel.

Task level training equipment requirements are assimilated into meaningful composites and referenced to the appropriate training objectives which they would effectively support.

Next, planned or existing equipment which have potential to satisfy the training requirements are analyzed and the efficacy of their use in the training program evaluated.

Recommendations as to the types and numbers of equipment necessary to support the training of the flight crews are developed based upon requirements, available and planned resources, schedule and cost.

The task analysis revealed that the same basic tasks are performed in operating the Spacelab subsystems in support of all types of payloads although, for pallet only modes, operator tasking is reduced by elimination of the module environmental control system (ECLS).

With the possible exception of the IPS activities, both nominal and contingency operation of Spacelab subsystems are procedural (step-by-step), follow a logical cause and effect relationship, are of low to moderate complexity and, to a great extent, can be scheduled.

All tasks identified on the training analysis worksheets were analyzed and summarized according to on-orbit equipment group operations, then converted into categories of instruction and objectives of instruction within each category. Personnel assignments, per NASA job descriptions, were made against each training objective.

The training equipments identified on the training analysis worksheets were assimilated into composite training devices and grouped according to training equipment types - mockup, part task trainer/ simulator, actual equipment and special interface equipment. "Actual equipment" consists of restraint devices, flight planning kits, pressure garments, etc. These data are included in Volume III of this report.

3.2 PROS AND CONS OF USING HI-FI MOCKUP, CVT AND ENGINEERING MODEL IN TRAINING

The training application and negative factors of the hi-fi mockup, CVT and engineering model are summarized in Table 3-1.

Table 3-1. Examine Pros and Cons of Using Hi-Fi Mockup, CVT and Engineering Model in Training

TRAINING EQUIPMENT	TRAINING APPLICATIONS	NEGATIVE FACTORS
CONCEPT VERIFICATION TEST/GENERAL PURPOSE LAB	• EXPERIMENT/CDMS PROFICIENCY TRAINING • INTEGRATED EXPERIMENT OPERATIONS EFFICIENCY TRAINING • MISSION EXPERIMENT SIMULATIONS	• CANNOT SUPPORT FULL TRAFFIC MODEL • CANNOT SUPPORT CVT AND TRAINING FOR TM-3 • APPROXIMATELY SAME BENEFITS COULD BE GAINED BY INTEGRATING PART TASK TRAINERS
ENGINEERING MODEL	• SPACELAB SUBSYSTEMS OPERATIONS AND MAINTENANCE PROCEDURES TRAINING	• REQUIRES MODIFICATION FOR USE AS TRAINER • TRAINING MODIFICATION DEGRADES USE FOR GROUND CREW TRAINING AND SUSTAINING ENGINEERING
HI-FI MOCKUP	• PROCEDURES TRAINING • SPACELAB FAMILIARIZATION • UPGRADE TO SPACELAB TRAINER	• AVAILABILITY FOR MODIFICATION AT JSC

The design of the CVT/GPLS limits it application in the Spacelab training program to Spacelab systems/experiment interface (proficiency) training and experiment operations (efficiency) training of payload and mission specialists. This type of device would probably prove to be very beneficial for integrated experiment operations, CORE use and integrated experiment CDMS/experiment interface/experiment operations interaction training. Further, flight data file development, crew activity planning and similar functions could be supported with such a device.

As EM-1 is functionally and dimensionally identical to the flight unit, includes the AFD PSS workstation and Orbiter interface adapter, all Spacelab O&M procedures can be performed on the EM as they would

on the flight unit in a 1-G environment, with the exceptions noted above. In addition, as the components are identical to the flight hardware fault isolation, item remove/repair/replace actions can also be performed within the context of the 1-G environment.

Modifying the EM to make it an efficient and effective training device would be quite costly and may detract from its effective use as an inflight maintenance support or sustaining engineering tool. The EM could in its present form, support habitability, familiarization, safety, both primary and refresher subsystem operations and maintenance and, to a limited extent, integrated flight crew operations training.

The Hi-Fi mockup is a sophisticated, detailed, full-scale representation of the physical elements of the Spacelab module. The physical characteristics of the components, subsystems and structures are representative of the flight unit design. The Hi-Fi mockup is planned to be used by JSC as the Spacelab 1-G trainer. The trainer is to be used in support of flight crew procedures training, hardware development, and flight crew training exercises for EVA, safety, stowage and habitability operations.

It is recommended that the mockup be upgraded to full trainer status in the subsystems areas. Experiment areas would remain as envelope fidelity only. The control and display elements would be electrically/electronically connected to replicate their system operating functions and be controlled through an instructor's console. CDMS display formats and control capability may well be capable of being simulated through an "intelligent" terminal, microprocessor approach as the functions it performs are, predominantly procedural in nature.

3.3 EVALUATION OF INCORPORATING CREW TRAINING INTO LEVELS II AND III INTEGRATION ACTIVITIES

The Level II integration facility consists of flight hardware and a series of electrical and support equipment to simulate Orbiter resources, supply power, provide operator control and display and test and services. The Orbiter interface adapter will simulate the Orbiter; it will include a PSS simulator, Spacelab/Orbiter signal simulator and power distribution.

The facility may be used for experiment activation through the actual Spacelab interfaces and to provide limited experiment operations. Constraints on operation are imposed by the experiment systems such as booms, etc. which may not be operated prior to launch. The Level II integration facility should be used for refresher training only. In addition to the limited experiment hardware operations capability, Level II integration will be accomplished over a period of approximately 5 days of 2-shift operations ending 2 weeks before launch. Under these time constraints the facility cannot be recommended for basic training.

The Level III integration facility consists of flight experiment hardware and electrical and support equipment to simulate Spacelab data interfaces, data handling and power distribution. The facility may be used for experiment activation through flight type interfaces, but not in the actual environment. The experiments may be constrained from operation at this time. The Level III integration activity is too close to launch to be acceptable for primary training. It will be suiteable for refresher training on activation/operation procedures.

3.4 TRAINING EQUIPMENT RECOMMENDATIONS

The type of equipment recommended for support of Spacelab subsystems, STS/SL/Payload Interface and Integrated Operations training for various flight loads is shown in Figure 3-1.

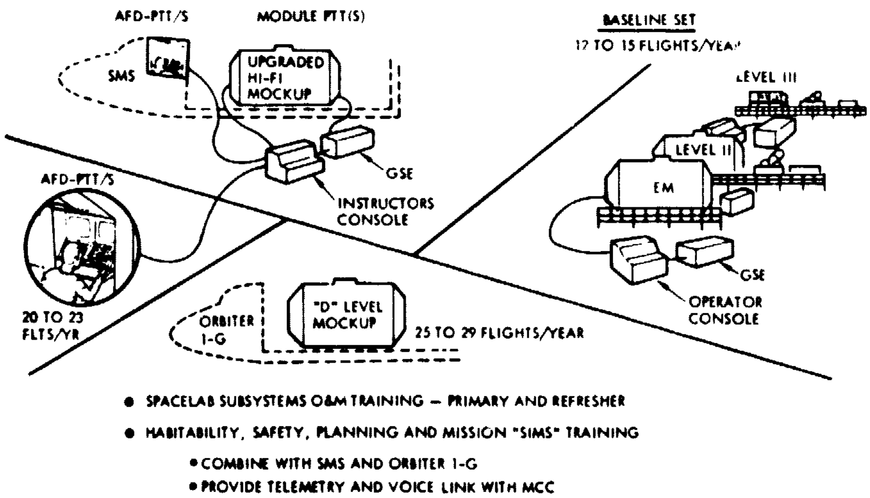


Figure 3-1. Training Equipment Recommendation

12 to 15 Flights/Year

The baseline equipment set consists of an AFD Part Task Trainer/ Simulator and Module PTT(S) with required GSE and Instructor's console for primary instruction. The EM and Levels II and III integration facilities would be used to supplement the primary training.

As previously described, the Spacelab subsystems manned operations tasks in both the AFD and Module require a training device of no greater than trainer level complexity, except for IPS operations. Interconnection of the two through an instructor's console would enable their independent or integrated use. Because operations and displays are not dynamic but discrete, and control/response actions are relatively slow, control of components for malfunction insertion or level changes can be performed manually through the instructor station.

If the AFD-PTT/S and Module PTT/(S) are incorporated into the SMS, MDM inputs to the SL and outputs to the MDM could also be implemented through the instructor console. This arrangement could effectively support all JSC Spacelab operations, interface and integrated simulations training requirements. However, the lack of experiment equipment precludes actual hardware operations experience in this area.

A comparison of the recommended trainer with the six million dollar Spacelab simulator is shown below.

JSC Simulator	TRW Alternative
• Basic interior module and AFD structure	• Same (Hi-Fi mockup)
• AFD C&D (plug-in)	• Similar-intelligent terminal's (MDM and RAU)
• Actual flight computer (2)	• Commerical mini or micro processor (if required)
• Full computer driven simulation of all SS and CPSE operations and phenomena	• Full functional representation of SS and CPSE operations
• Direct interface to SMS computer and software	• Isolated from SMS computer by instructor's console

JSC Simulator	TRW Alternative
• Preprogrammed malfunctions	• Remote manual malfunction insertion
• Dynamic telemetry data	• Possible - could use canned tapes
• No visual-SMS supplied	• Same

The functions are basically the same, however, the TRW alternative uses the advancing state-of-the-art in mini/micro processors to minimize costs.

20 to 23 Flights/Year

The addition of another AFD trainer to the baseline equipment set would nearly double the Spacelab training capacity. The flight load which can be supported by the basic set is dependent upon the types of payloads. Pallet only configurations comprise nearly 50 percent of the missions.

25 to 29 Flights/Year

The training equipment described above can be made to support 25 to 29 flights per year with the addition of "D" level Spacelab mockup.

A low systems fidelity, high envelope fidelity mockup would enable off-loading of the Module trainer for basic familiarization, safety, and mission "SIMS" walk-through training of Payload Specialists.

3.5 SUMMARY AND RECOMMENDATIONS

The results and recommendations of the crew training tasks are summaried in the form of answers to the special questions from the mid-term briefing; as follows:

1) Evaluate impact of remote control on task analysis.

   No significant changes from initial analysis. Some modifications as to how and where functions are performed. Simplified control and display panels.

2) Reexamine need for $6M Spacelab simulator.

   Training devices required but full simulation is not mandatory.

3) Examine applicability of Hi-Fi mockup, CVT and EM to training.

Hi-Fi Mockup	-	Upgrade to trainer status on subsystems, lo-fi mockup of experiment C&D
CVT	-	Can be used for proficiency development
EM	-	Use for refresher training.

4) Examine possibility of incorporating Levels II and III integration into crew training.

Use for refresher training with crew as test engineers.

U.S. GOVERNMENT PRINTING OFFICE: 1975—671-548/1286